Final Report

Design for Sustainable Communities

Bioclimatic Kit House

Moorea, French Polynesia

May 2009

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ABSTRACT

Due to French Polynesia's expensive housing and land properties, tropical climate, and a history of cyclones destroying homes, society needs an affordable, comfortable, and cyclone resistant housing option. After cyclones in the early 1980s, the MTR (French acronym for Territorial Houses of Reconstruction) kit houses subsidized by the French government, were constructed throughout French Polynesia. In rapid response to the disaster, the MTR’s design focused on affordability, ease of construction, and structural integrity, but lacked consideration for its thermal qualities that currently make the MTRs unlivable during the day due to high interior temperatures. The people of French Polynesia need a better-designed affordable housing option, in which they can comfortably complete their daily activities. Through thermal modeling of the fourth prototype designed by the Office of Polynesian Housing (OPH), we believe that the house will continue to be too hot and uncomfortable without more design alterations or additional technologies to increase thermal comfort through air circulation. Therefore, we have suggested the use of energy-efficient fans as well as roof paint that reflects 52% of the sun's near-infrared radiation while allowing for an assortment of color choices (Akbari 2009). We will test these suggestions physically and digitally in August 2009 in Moorea on the built prototype .

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I. BACKGROUND

French Polynesia is a moderately developed group of islands that are an overseas territory of France with their own autonomous government. While the current French Polynesian government is leaning towards independence, they are currently highly reliant on imported goods and financial assistance from France (Fava, March 2009). Tourism is the largest industry, with 76.1% of the population employed in the service sector (CIA 2005). Other employment sectors include pearl farming, deep-sea fishing, and agriculture. The current average annual family income is US $18,000, while the average single-family dwelling costs $600,000 (Brown 2006). The high average is distorted due to the soaring cost of land and high-priced homes owned by non-natives, although many natives have had land in their families for generations (Fava, March 2009). With the increasingly modernizing culture and lack of industries on the islands, there have been rising living expenses attributed to high importation costs (Brown).

The need for affordable housing is being addressed by the Bioclimatic Kit house or MTR, which costs between $80,000--$100,000. The MTR house began as a government subsidized cyclone resistive structure on the islands of French Polynesia as a result of the major cyclones to hit the islands between 1982-1983 (Brown 2006). These became even more important after typhoon William hit in 1992 and the kit houses were some of the only remaining structures across the islands. This led to the government readdressing housing issues with the MTR II design. The houses began being sold commercially as an affordable housing option for Native Polynesians by the Office of Polynesian Housing (OPH) in 1995. With 500 MTRs sold yearly, about 350 receive subsidies from the French government. The houses are ubiquitous throughout the islands, and remain one of the only housing options for the average family. While these houses have been attractive for their low cost, low maintenance, and hurricane-resistive performance, they have had the problem of trapping excess heat, leading to unbearable conditions for residents.

The MTR has been altered four times in an attempt to improve its thermal performance, while maintaining affordability and structural integrity. The project is being carried out by an agency of the Ministry of French Polynesia, the Office of Polynesian Housing (OPH), who is responsible for the design and dissemination of the MTRs. In 2006, the third MTR was digitally modeled and analyzed by a previous group of UC Berkeley student researchers, who made design suggestions and proposed an on-site monitoring schedule within a nine month time frame, prior to its manufacture. With lack of government funding to build the prototype, the plan was never realized and the third prototype was never built and monitored. OPH has currently designed a fourth prototype, with the intention of construction this summer to monitor and analyze it throughout the year before it is mass produced and distributed. We will be digitally analyzing the fourth design for the scope of this report while planning the physical testing and monitoring of the MTR prototype on site this summer.

II. GOALS

Our goals for this project have changed due do the gradual pace we have received information over the time frame of the entire semester. Our goals have been extended to include our summer project proposal during our on-site analysis of the newest MTR prototype.

OVERARCHING GOALS

- Increase thermal comfort of house to adequate level for the standards of those living in French Polynesia
- Post Occupancy Evaluation of older MTR designs to address what is specifically needed in new designs based on social and cultural considerations.
- Build up local industries to support lower cost MTR components (timber, fan, paint)

IMMEDIATE GOALS

- Digitally model 4th MTR prototype in Ecotect
    - Enable easy manipulation of design features affecting thermal properties
    - Produce analysis of thermal efficiency and comfort, based on climate and energy usage from specific scenarios.
- Use of data for research and modification to improve thermal conditions of latest MTR
    - Make a comparison of benefits and losses of current design versus the design with our suggestions in terms of thermal performance and cost.

  - Scenarios include near infrared reflective paint, efficient fan technologies.

FUTURE PROJECT GOALS AND SUMMER RESEARCH PROPOSAL

- Understanding thermal sensor equipment, installation, and usage
- On-site MTR prototype testing and analysis with possible design suggestions such as window size and placement, shading overhangs and house orientation.
- Qualitative Semi-structured Interview to develop future Post Occupancy Evaluation
- Influence Office of Polynesian Housing's (OPH) design methods
- OPH software knowledge
- Introducing software knowledge and sensor capabilites to students on the island
- Project and Budget proposal for the summer

III. METHODS

LIMITATIONS

The relationship between previous groups and the Moorea on-site team has shifted with our project because our main contact, Madeline Fava, an architect based in France, who was once the lead architect on the project is no longer directly involved in the house design (though she is now taking a new role in MTR design over the next year). The MTR is now solely administered through the Office of Polynesian Housing (OPH), which due to bureaucracy caused extreme lag in communication and a shortage in providing needed information. Our lack of direct contact with a primary source, and receiving crucial data, has profoundly inhibited our ability to conduct a thorough and accurate thermal analysis. Assumptions that we made about the current design will be noted and stated within the report.

APPROACH

We studied the previous Design for Sustainable Communities (DSC) groups' reports to attain ideas on how the earlier groups approached the project. The project group from 2006 studied the thermal properties of the third iteration of the MTR. One member of their team also traveled to Moorea during the semester, and recorded detailed field notes, while being able to get most of their group questions answered on-site. They made many design suggestions including the addition of the roof vent, and proposed a nine month plan to oversee the analysis of the prototype onsite. The plan was never carried out, as funds to complete the project were never attained, and the prototype was never built. The 2007 DSC group performed a full materials analysis of the MTR. They were looking to find the most sustainable materials for construction by researching which materials were available, viable and appropriate in French Polynesia; these included coconut, bamboo, and Caribbean pine. Their analysis took into account the full life-cycle of the materials: the amount of material available, product and transportation cost, and the potential for production on the island. We have used this information to enhance our understanding of the project.

Our approach has differed in a few ways: we have not had a direct contact from OPH, and with the extra time waiting for the drawings, we were able to thoroughly study the context of the issues that the MTR addresses as well as analyze the different physical technologies that can be added to the building design to enhance thermal comfort. We did our modeling in Ecotect while 2006 used Energy 10. On a broader scale, OPH is preparing to build the prototype of the fourth MTR in July 2009 with intent of our research group installing and running monitoring equipment to analyze various thermal and energy-saving qualities of the house.

We began by spending a considerable amount of time researching design for hot and humid climates to familiarize ourselves with various design methods appropriate for this specific environment and climate. In hot and humid climates, there is an emphasis on natural ventilation. Structural mass is a liability and costly, so structures should be light-weight to allow for sufficient air movement without the mass absorbing heat. In the case of French Polynesia, these light-weight structures must also be hurricane resistant. Often houses are set on stilts to decrease interior temperatures through enabling wind circulation under the house as well as reduce conductance from the earth. High ceilings are used to allow the air to stratify, and vent placement at the ridge beam allows the hottest air to escape. Qualitatively we can see the use of these design techniques in the latest MTR design , but we are unable to quantify the amount of air flow and passive cooling occurring because of the lack of design details we received from OPH.

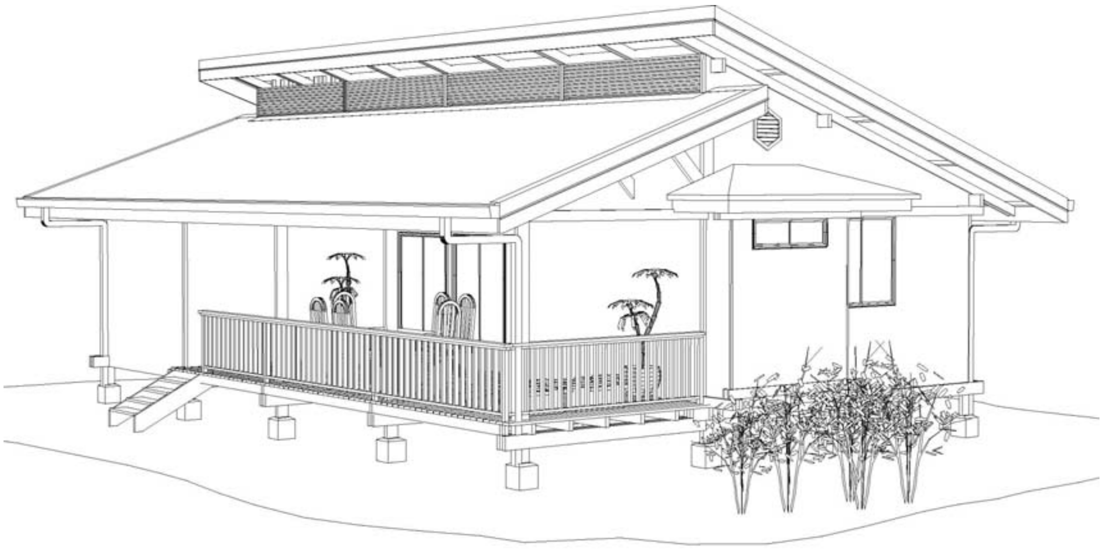


***Figure**: Perspective of fourth prototype MTR (Office of Polynesian Housing)*

The 3-tier design approach of cooling a house are by a) heat avoidance, reducing solar heat gains, b) passive cooling, use of ventilation to shift comfort levels to higher temperatures, and c) mechanical equipment, used to cool what the other two methods cannot. We have researched combining these approaches for optimal thermal performance. We are recommending a hybrid system, by combining the use of a low-energy highly efficient fan with the natural ventilation system. While the building design continues to collect heat, we are proposing increasing air velocity with a fan to raise the comfort zone sufficiently to include high indoor temperatures. Although the building is not using air conditioning, people will feel more comfortable.

THERMAL ANALYSIS: ECOTECT MODEL

The 3D model was generated with Autodesk's Ecotect, which is a program for building design and environmental analysis with a wide range of simulations and functions. The program provides analysis of the operation and performance of building design to create energy efficient and comfortable designs. We are using Ecotect to digitally model the house and simulate the tropical environment to understand how the building will perform. We can then use this model to easily change variable building features such as roof details, insulation, window size and placement, building orientation, and shading in order to test and analyze possible design improvements. With modifying the building, predictions that decrease interior temperature and increase airflow will signify successful design improvements that could be changed on the prototype.

ECOTECT MODEL

We were never given accurate sections of the building design, material properties, insulation specs, or roof vent dimensions and details. We were given a plan, a perspective drawing, and 54 framing details of the wooden members. Although the framing details were not adequately labeled, we organized them logically based on the plan and perspective drawings to figure out which drawing went to which component of the house. We then used AutoCAD to draft proper plans, sections, and elevations. The framing details included most of the general heights and lengths of the building components, but we had to make some calculations about a few distances, such as the length the overhang extended from the building. We did this by using geometrical proportions with a build up of construction lines in the AutoCAD drawings.

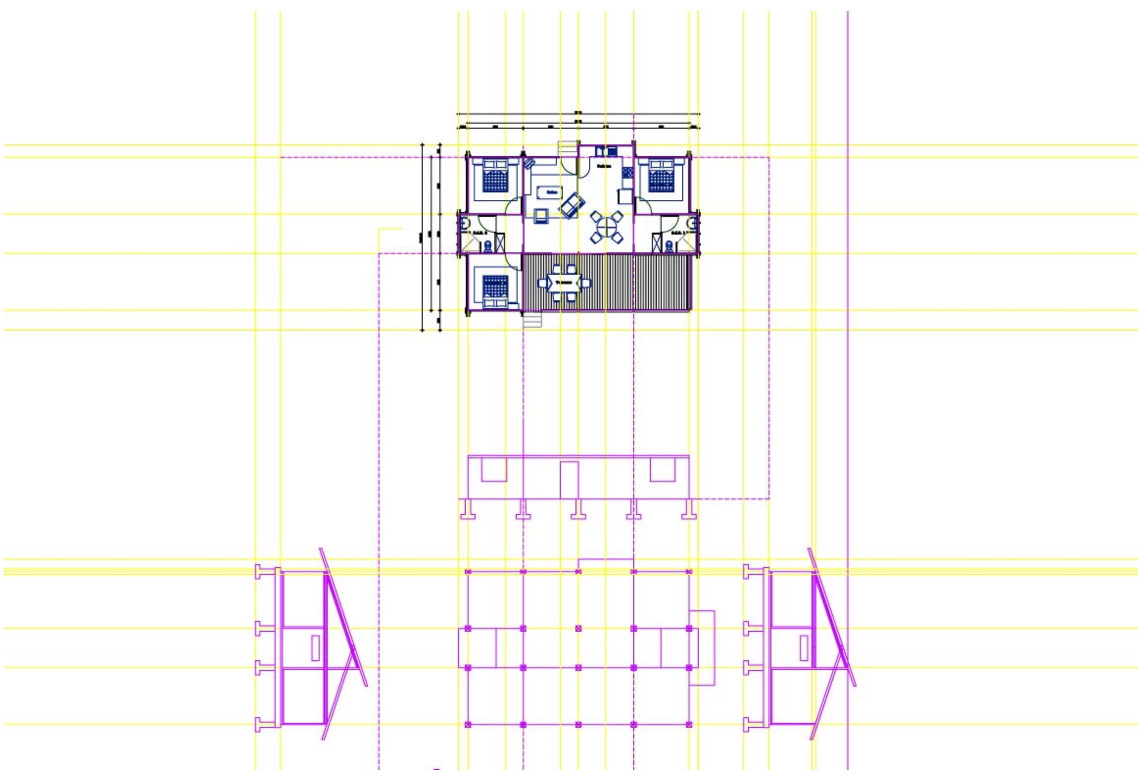


Figure*: Plan of MTR with construction lines to form AutoCAD sections and elevation*

There were also some discrepancies between the framed member drawings and the plan drawing. For instance, some of the window placement varied from the framing details to the plan. We decided to base the window placement off of the plan only, but correspond the window sizes with those used in the framing.

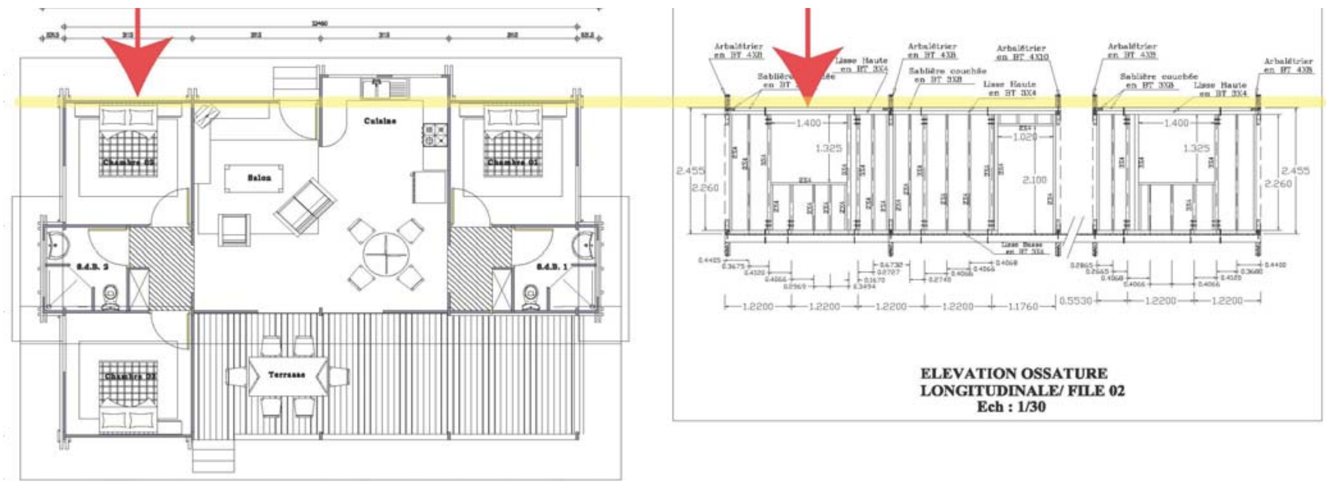


Figure*: Plan of MTR (left) & Framing Detail Elevation (right) of 4th prototype of MTR (Office of Polynesian Housing)*

Without being given the necessary information on the roof design, we were unable to accurately model the roof vent or analyze its stack effect. These limitations and assumptions will have an effect on the output analysis, but the 3D model can be adjusted onsite once the proper information is gathered.

INPUTS

General Building Inputs

Climate and Site

The climate varies throughout French Polynesia. Moorea more specifically is apart of eastern group of Windward islands of the Society Islands which are a subset of the French Polynesian Islands. We were not able to collect microclimate data for Moorea, but in Ecotect you can import weather files which provide detailed weather information over the course of the year. As there was no weather profile for French Polynesia, we substituted by importing the Singapore weather data file to simulate the typical tropical thermal performance. The climates are similar, with the same wet and dry seasons, and similar average temperature throughout the year. Moorea's specific latitude and longitude were used, and the orientation of the house was set to Northeast, in line with how it will be constructed at the Gump Research Station.

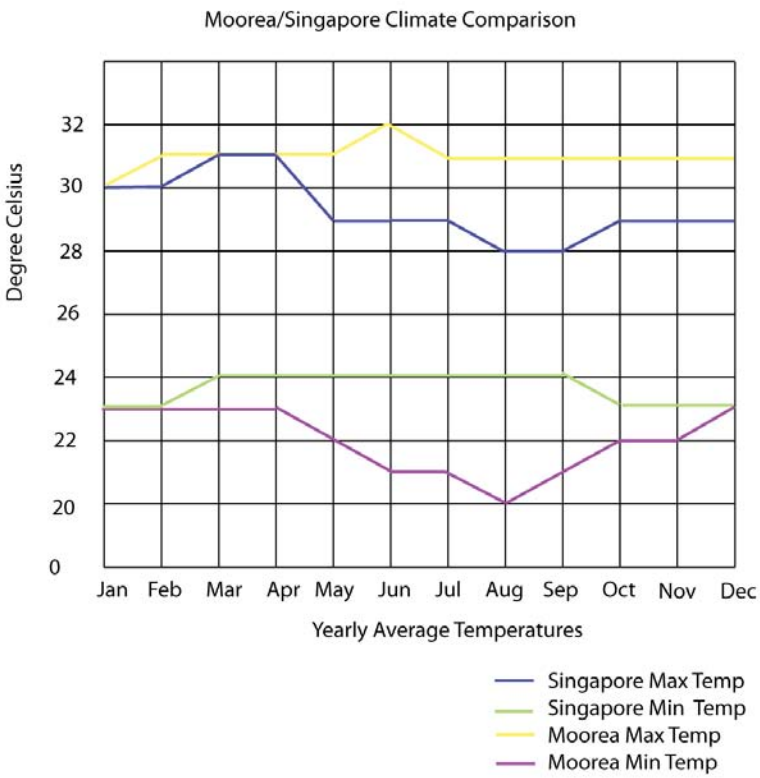


***Figure**: Comparison of Moorea and Singapore average yearly max and min temperatures by month (Colonial Voyage)*

Comfort Band

To reflect a desirable cooling envelope for natives on the islands, we adjusted the comfort band based on a psychometric chart produced by the LDS comfort-cooling index. According to the North American standards, the maximum dry bulb temperature for physical comfort is 30° C, while in French Polynesia the maximum dry bulb temperature is 32° C, and the minimum dry bulb temperature is 26° C. If the conditions of the MTR can be kept within the range of 26-32 °C, then the occupants are considered to be thermally comfortable.

Zone Inputs

Zones in Ecotect, designate homogeneous enclosed volumes of air, such as rooms. Each zone is given particular properties to simulate the actual environment of the space. It is here that we input design values about the occupants including their clothing levels(value given for amount of clothing worn), activity levels (value for the biological heat output), and a customized schedule. Within each zone, we designated air changes/ hour (ACH), infiltration rates, and internal gains, which affect heat gains and thermal comfort for each zone. Occupancy properties are based on an average 6 person family, using generalizations about about family life based on field notes from the Moorea 2006 group. We also incorporated a custom schedule; a typical family rises at 4am, cooks a large meal of fish and coffee, and is out of the house by 6am. Schools start at 7:15 am, and the house is usually empty until 2:30pm. Hot showers occur around 4pm, dinner is served at 5pm, and the family is asleep between 7-9pm. (Moorea 06) Internal Gains were calculated from lighting and small power loads per unit floor area, W/m2. According to the 2006 field notes, the main electricity loads come from the lights, washer, iron, small refrigerator, minimal stove usage, and a television.

ZONES

Bedrooms

- Activity= 40 W assuming just sleeping happening
- Internal gains
  - lighting = 100 W
  - radio = 5 W
- Clo: 0.2 clo based on light underwear

Living Room/ Kitchen

- Activity= 100 W based on cooking
- Internal gains
  - Iron = 1100 W
  - stove=

    - washer=840
    - TV = 100 W
    - small refrigerator (12-14 cu ft) = 475 W
  - Clo: 0.4 based on light clothing levels of shorts and tank top

Bathrooms

  - Activity= 70 W based on sedentary movement
  - Internal gains
    - lights= 100W
  - Clo: 0.0 based on nudity.

(PSNH 2009)

ADDITIONAL BUILDING FEATURES

In response to the current limitations faced in our contact with OPH, we decided to research building features that can be controlled by the occupants to give them options in addressing their MTR in relation to their thermal comfort. These features are particularly useful to past MTR house models that numerous families are currently living in. Most families living in these older MTR models do not have the extra time and money to focus on restructuring their home for the sake of their thermal comfort, therefore making the additional technologies of high value. The two main additions that we focused on and will be analyzed on-site during the summer are the Gossamer Fan blade Technology and LBNL's Near-Infrared (NIR) Reflective Paint.

GOSSAMER FAN BLADE TECHNOLOGY*:*

Through reading past reports and field notes as well as conversing with people who lived in French Polynesia, we learned that fans are used in a majority of homes. Electricity bills are extremely expensive on the islands ($.375USD/kWh) making maximum efficiency of the fans increasingly important. Professor Ed Arens' suggested we research the effectiveness of the Gossamer Wind ceiling fan. The fan, developed by the Florida Solar Energy Center, has new aerodynamic blades and energy efficient light kit uses 40% less energy than a typical fan on the market today. The fan circulates more air while using the same amount of power as a regular fan. In addition, the light kit is equipped with motion sensors and low-energy bulbs for minimum energy use and maximum efficiency (Gossamer). We are proposing the idea of incorporating a highly energy-efficient fan to greatly increase air movement, which in turn increases thermal comfort.

NEAR INFRARED REFLECTIVE PAINT:

As demonstrated in the 2006 group analysis, much solar heat gain comes from the roof. Solar heat gain of metallic roofs is determined by its coating (in this case, paint), and it is a cultural preference to paint the roofs dark green or red. This increases roof surface temperature, compared to a white roof, and this heat transmits into the building to increase internal temperatures. Ideally, a white-roof is preferable to reflect visible and near infrared radiation, but working within the cultural preference framework, we are proposing the use of "cool paint" paint developed by the Lawrence Berkeley National Laboratory which absorbs very little of the near infrared radiation from the sun that composes more than half of the radiation. While we wanted to model such changes in Ecotect, we could not effectively gather the information needed to make the changes to the model in relation to its affect on thermal comfort. We hope to gather more information site, and make changes accordingly.

IV. RESULTS

LIMITATIONS

Due to our lack of information, the house modeled may not accurately reflect the actually 4th MTR design. Although this greatly hinders are analysis, we have learned from the process, and consider these results a trial-run of the full thermal analysis we will be conducting on site. We are still affiliating ourselves with the program and its capabilities; our analysis consists of general input options given in the program such as the weather file, generic material properties, and basic calculations, but we hope to have a full understanding of its scripting capabilities before our field work commences. We also would like to focus on using Ecotect to look at relationships and qualitative assessments about the MTR. The 3D capabilities of the program are beneficial for a general understanding of various aspects of the MTR design, but we need to use monitoring equipment to more thoroughly address design specifics with numerical data collection. Through gathering this data on-site, we can input the information back into Ecotect to generate more accurate information.

ECOTECT RESULTS

We tested 3 different scenarios of the MTR in relation to Thermal Comfort:

1. **Required Air Velocity of Current Condition**
    - Assuming no air movement we wanted to see the necessary air movement required to achieve thermal comfort

2. **Percent of Time Users Experience Discomfort**
    - By month over time frame of entire year

3. **Comparison of Current House Conditions vs. MTR with Air Movement** (fan use)
    - We tested these conditions for the hottest and coolest time frames of the year as predicted by Ecotect
    - (Air Movement Defined by Air Changes/ Hour (ACH): 1 Fan/bedroom & 2 in Living Room)

In analyzing the current condition of the house we assumed no air movement (2 ACH) from natural ventilation (which would be minimal due to low winds) to produce a worst case scenario. In reality, we hope that the roof vent would also have an affect on air circulation within the house, but since data on the rate of air movement from the interior space outward through the roof vent is not available until we test the house on-site, we did not model this condition.

For all of these scenarios, we focused on studying the bedrooms (3) and the kitchen/ living space (1) because these are the most used spaced inside the house. The bathrooms are however, always too hot and we did not consider putting a fan in these small and minimally used spaces. When referring to an increase in air movement we are including the ACH of the gossamer fan with placing 1 in each bedroom, and 2 in the kitchen/living space. The quantity of fans placed in each space was based on the the Gossamer fan's size and range of air movement in relation to the volume it was supplying. In modeling the ACH of the fan in Ecotect, we used the specified values from the Florida Solar Energy Center's research. It was stated that each fan could move 4200 cubic feet of air per minute (Parker). This value was converted to the volume of the room per hour, which is what Ecotect accepts as an input (see Appendix for calcs). ACH for the bedroom was calculated at 177 ACH and the kitchen/living space at 120 ACH. All model predictions are in relation to the comfort band adjustment for standards of those living in French Polynesia at 26-32° C

MTR LAYOUT

Figure*: Ecotect Model of MTR (left) and Plan of MTR (right)*

Red= Bedrooms, Purple = Ktichen/ Living Room, Blue = Bathrooms

THERMAL COMFORT:

Required Air Velocity of Current Condition

In looking at the current condition of the the house, it is necessary to have some means of air movement throughout all rooms of the house. The kitchen/ living space is the most comfortable, though still needs at least 1.05 m/s air velocity, in relation to the rest of the house that needs 2.10 m/s or higher to reach a state of thermal comfort for the occupants

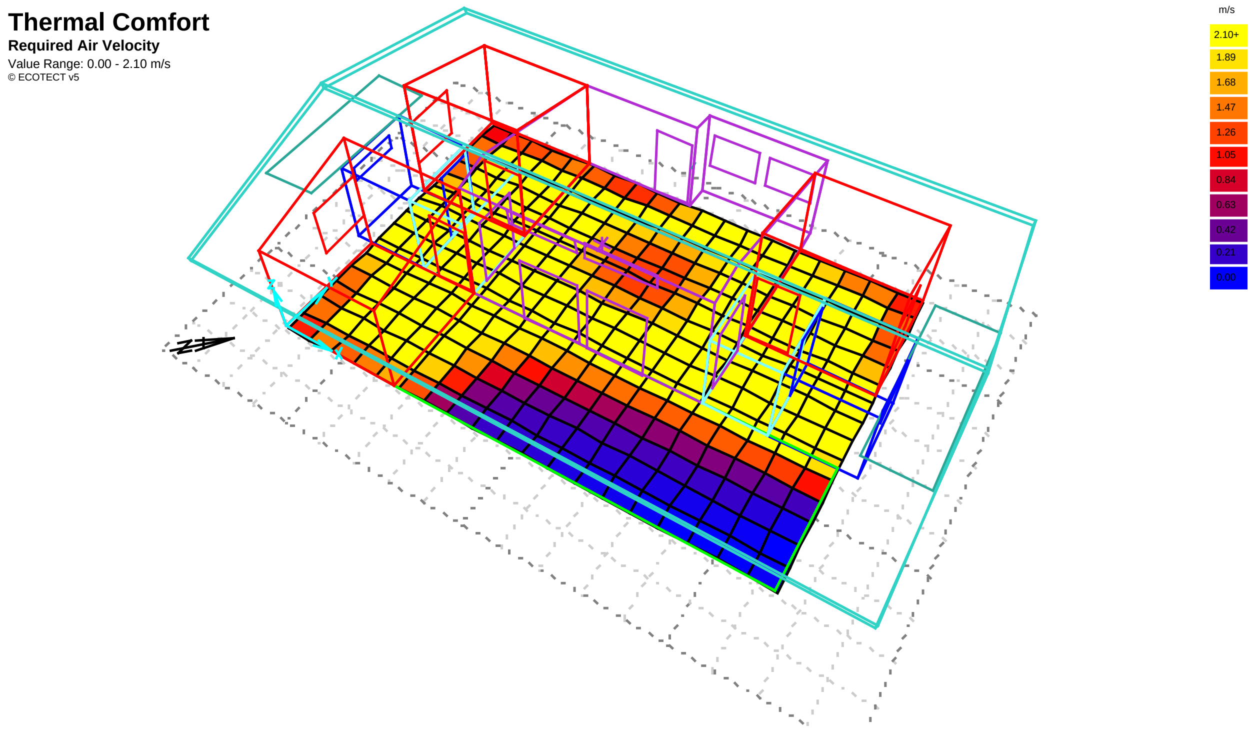


***Figure**: Ecotect Model: The yellow spaces reference areas that need air movement above 2.10 m/s. The blue space is the deck (exterior space), which is covered by a roof overhang. The contrast between the two spaces shows why occupants do many activities outside in a shaded area.*

THERMAL COMFORT:

Percentage of Time Occupants Experience Discomfort Per Month Over a Year

We also looked at the amount of time that people would be in a state of discomfort (outside their comfort band) throughout each month over the time frame of a year. The goal in this analysis was to look at how much we could decrease discomfort by increasing air movement in the house. In the current condition (assuming no air movement), the house is always too hot, but in increasing air movement (through increased ACH from fan) we can decrease discomfort levels from heat by 67% in one year.

DISCOMFORT DEGREE HOURS
Comfort Band: 26-32°C

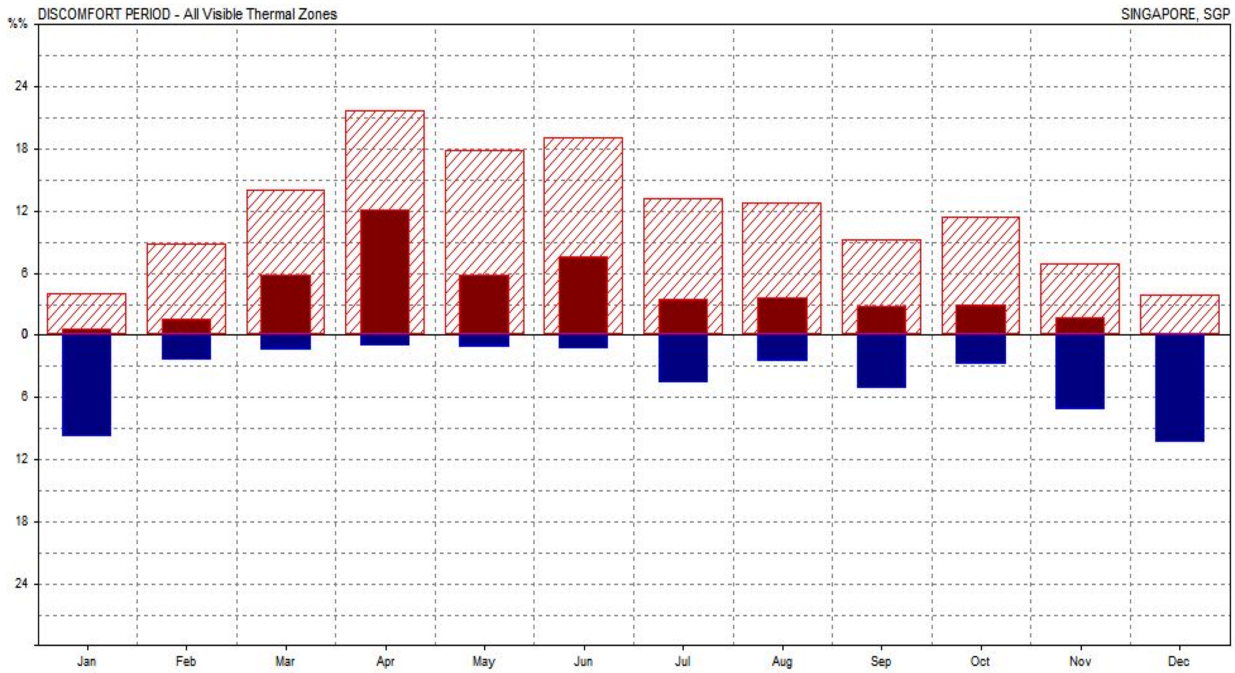
CURRENT CONDITION
(Assuming No Air Movement)

MONTH	TOO HOT (%)	TOO COOL (%)	TOTAL (%)
------	--------	---------	------
Jan	4.03	0.00	4.03
Feb	8.82	0.00	8.82
Mar	14.01	0.00	14.01
Apr	21.70	0.00	21.70
May	17.81	0.00	17.81
Jun	19.17	0.00	19.17
Jul	13.27	0.00	13.27
Aug	12.87	0.00	12.87
Sep	9.27	0.00	9.27
Oct	11.49	0.00	11.49
Nov	6.88	0.00	6.88
Dec	3.86	0.00	3.86
------	--------	---------	------
TOTAL	143.2	0.0	143.2

WITH AIR MOVEMENT
(Based on ACH of Fan)

MONTH	TOO HOT (%)	TOO COOL (%)	TOTAL (%)
------	--------	---------	------
Jan	0.60	9.31	9.91
Feb	1.64	2.12	3.76
Mar	5.81	1.24	7.06
Apr	12.12	1.04	13.16
May	5.91	0.87	6.79
Jun	7.53	1.11	8.65
Jul	3.49	4.54	8.03
Aug	3.73	2.49	6.22
Sep	2.74	5.03	7.78
Oct	2.99	2.72	5.71
Nov	1.70	7.01	8.72
Dec	0.17	10.22	10.38
------	--------	---------	------
TOTAL	48.4	47.7	96.2

***Chart**: Ecotect Chart- Current Condition vs House with Air Movement. Percentages calculated per month. Through increasing air movement we can decrease discomfort levels from heat by 67% in one year.*



***Graph**: Ecotect Model. The red stripped bars are the current condition, which indicate that occupants are always in a state of discomfort. The solid colors (blue and red) indicate the house with air movement, showing a decrease in discomfort from heat, and an increase in discomfort from cold. The increase in blue is acceptable because this signifies that the occupant would turn the fan off. The X-axis displays each month, with April being the hottest time of the year. The Y-axis indicates % too hot or too cold, with the deviation from zero being beyond the comfort band of 26-32 °C.*

THERMAL COMFORT:

Percent Dissatisfaction of Current MTR Conditions (Assuming No Air Movement) vs. MTR with Air Movement (In relation to ACH by Fan)

Background to Thermal Comfort Percent Dissatisfaction

Percent Dissatisfaction is based on Predicted Mean Vote (PMV) which refers to a thermal scale (-3 to 3) developed by Fanger and later used as an ISO standard (Charles). As PMV deviates form 0 (neutral) in either direction, the Percent Dissatisfaction increases. 100 % is the maximum number of people that can be dissatisfied with their thermal comfort conditions, but the minimum is 5 % considering that you can never please all the people all the time. Clo and

Metabolic Rate (activity) are essential in defining accurate results, which we based on field notes from previous Moorea group in 2006. However, inaccuracy in measures of clothing insulation and activity level will affect Percent Dissatisfaction.

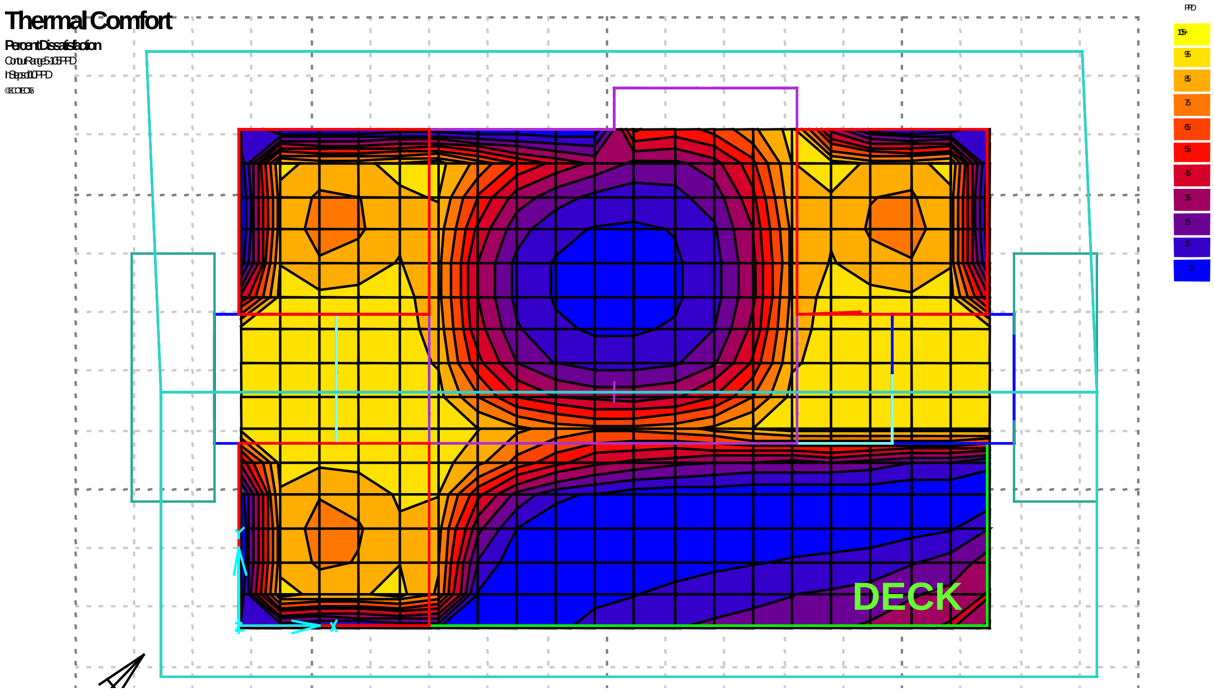
Fanger's PMV Model analyzes and combines four physical conditions of air temperature, air velocity, mean radiant temperature, and relative humidity (Charles). The PMV model was developed in the 1970s from climate chamber studies in which participants were dressed in standard clothing and completed certain activities while exposed to various thermal environments. Participants recorded how hot or cold they felt using the thermal scale -3 (cold) to 3 (hot) while in other experiments they adjusted their own thermal environment to create their own neutrality point. Various studies have been done on other conditions affecting thermal comfort level such as gender, building type, cooling systems, physiological adaption and outdoor climate all of which have found possible discrepancies with PMV. These models have become the standard of predicting thermal comfort, but their validity has been questioned and hence should be questioned in relation to field studies and analysis (Charles). It should be noted that thermal comfort is based on the individual, which therefore makes it extremely difficult to quantify, making all predictions questionable.

Results

In testing the current conditions versus conditions with air movement on the hottest and coolest day (as predicted by Ecotect), we wanted to see how thermal comfort would increase in relation to space. In both scenarios there is an increase in the percentage of people thermally comfortable in the bedrooms and kitchen/living space

Hottest Day: April 23 1 PM

Current Condition



MTR with Air Movement (Fan)

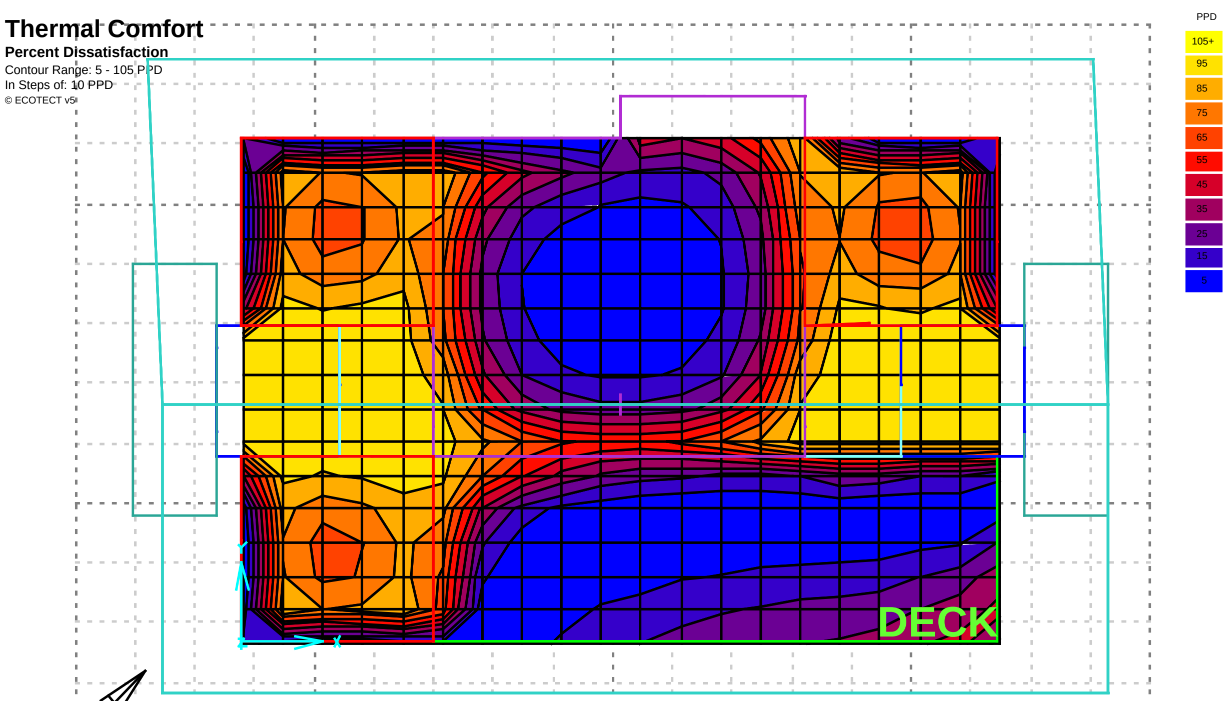
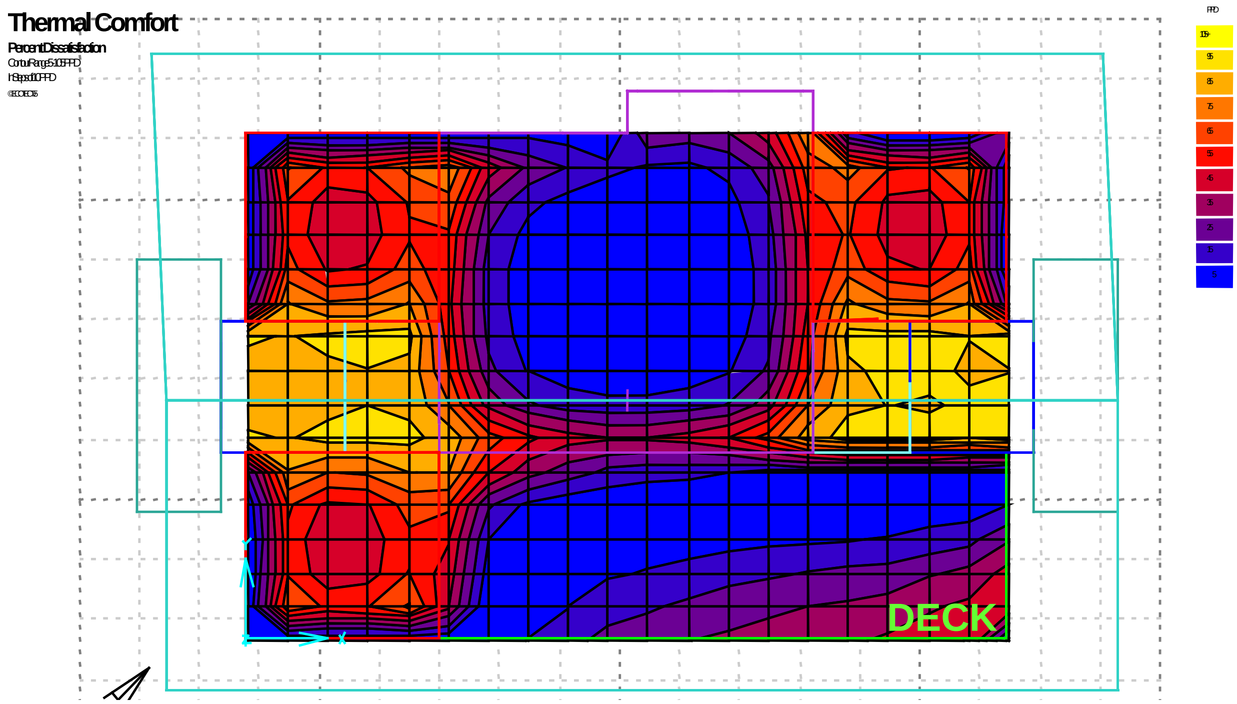


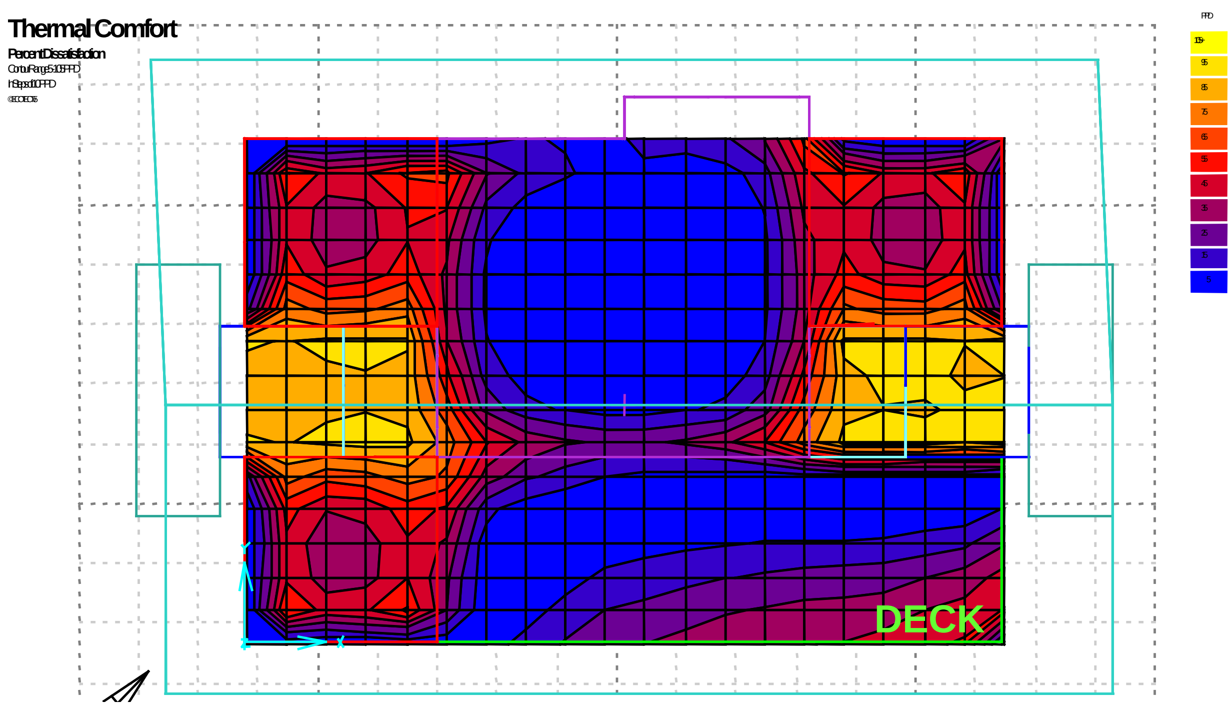
***Figure**: Ecotect Model: Hottest Day-MTR with Air Movement- The scale is based from 5% to 105% due to the fact that you can never please all the people all the time. 105% being the maximum amount of people that can be dissatisfied with their comfort conditions. The darker the color the less people dissatisfied = desired result.*

Coolest Day: Oct 22

Current Condition



MTR with Air Movement



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ECOTECT ANALYSIS CONCLUDING POINTS

MTRs are consistently hot all year due to the humid and tropical climate. This warm climate will not change, and there are only so many options to decrease interior temperatures of the MTR. Though our testing scenarios are not based on actually decreasing temperature, we are focusing on how to increase thermal comfort by increasing air movement within the comfort range of the French Polynesian community. We believe that without a mechanical cooling system it will be difficult to increase comfort therefore making the most appropriate idea to introduce a hybrid system of natural ventilation and passive cooling methods such as the fan. Circulating the hot air out of the house as well as preventing stagnant air will increase thermal comfort. Another significant factor contributing to increasing interior temperatures of the MTR is a dark roof. A dark roof needs to be analyzed and worked with either through applying some sort of near-infrared reflective paint or changing society's roof color preferences (which is not our goal, though widespread educational components to this issue might be beneficial). Though our results are preliminary, we can use our growing knowledge and understanding of Ecotect to easily manipulate design features based on the actual MTR on site to conduct further thermal analyzes.

DESIGN IMPROVEMENTS: ADDITIONAL TECHNOLOGIES

After we get accurate information on-site we can run the analysis on the current MTR conditions; we can then make necessary changes and improvements for positive feedback in relation to ventilation and temperature control. Once we have the two data sets we can compare the built prototype and the 3D model with our suggested design improvements. Improvement ideas include roof design with different insulation types and vent shape to ultimately make a more efficient/lower cost roof; window size, shading and placement to reduce solar gains; and possible interior low-ceiling removal to increase roof space and natural ventilation of passive cooling.

One simple design alteration that we researched was the usage of near-infrared reflective paint for the roofs of the MTRs. This paint was developed by the Lawrence Berkeley National Laboratory. It can be any color (like the dark green that the Polynesians prefer) but is spectrally selective so that it reflects the infrared radiation that will heat up the roof. As the roof color gets darker, more of the radiation is absorbed by the roof, and thus transmitted through the roof into the space below which causes an increase in the interior house temperature (Akbari 2009). While white roofs are the most effective color choice, they are not socially preferable, so the near-infrared reflective paint is a viable option that we will research further and test in the summer.

In addition to the near-infrared reflective paint, we researched the use of a highly efficient ceiling fan for use within the MTR. The blades of the fan have an aerodynamically engineered design that maximizes air flow without increasing energy use (Parker 2007). After a cost analysis with certain assumptions (Appendix I), the occupants of the MTR could save a minimum of $130 per year, and a maximum of $272 per year as seen in the table. The fan can also operate at a lower, yet adequate setting, using less than 50W of energy and thus increasing savings. The Ecotect analysis predicted that with increased air movement throughout the MTR, comfort can be raised to an acceptable level.

		Quantity	All on (hrs/day)	One on (hrs/day)	Watts	$/kWh	Cost/day	Cost/year	Saved (40%)
LIGHTS	**Max**	5	8.5	7	60	0.375	1.11	406.52	162.61
	Min	5	4	11.5	60	0.375	0.71	258.69	103.48
FANS	**Max**	5	8	0	50	0.375	0.75	273.75	109.50
	Min	5	2	0	50	0.375	0.19	68.44	27.38
						$ SAVED/ YEAR		Max Saved:	**272.11**
								Min Saved:	**130.85**

***Chart**: Current Cost vs. Improved Technology Cost.*

We want to focus our analysis on balancing thermal comfort and affordability. The latest model of the house has a complex roof that has measurably increased the price of the house; the roof design may be simplified with these additional products if the costs and performance out-do the new roof. We look forward to testing these additions on-site during the summer and beyond.

V. FUTURE WORK

PHYSICAL MONITORING

Due to the gradual process of working with a government agency, we spent much of the semester extensively planning our summer project proposal and research. Currently, we have tentative plans to travel to Moorea in August to analyze the physical MTR prototype. Either our selves or a Polynesian family will be living in the MTR, simulating a typical day of a local who would be using the house to accomplish their daily tasks such as cooking, cleaning, eating, washing clothes, and socializing. While on the island, we plan to install HOBO data loggers that run continuously and can be attached to a computer to download the data within a set time frame. These HOBOs will measure the temperature variations within the MTR. We have also purchased an anemometer to measure air velocities and humidity. As we modify the kit house (or possibly testing other built forms at the Gump station as to maintain our variables and controls) with our suggestions such as the cool paint and energy efficient fans, the HOBOs will log the thermal changes of the interior from these additional technologies.

In addition to the continuous data collection, we have a number of tools that we will use to analyze qualities of the house such as air flow and velocity, humidity, ambient temperature, and surface temperature within at set times throughout the day/month. The directionality of air flow is difficult to measure quantitatively, so we will use a tool that creates a thick, fog that can be emitted at desired quantities to visually track air movement. This fog can be emitted at the roof vent to see how much and where the air is flowing through the vent opening, at each window to see the effect of window openings, or at locations around the perimeter of the house for a qualitative analysis of the heat exhaustion to the exterior. Also, we will be using an anemometer to measure the wind speed at any location along with the temperature and humidity at that location. Lastly, to measure the difference of surface temperature, which has been shown to be related to interior temperature (Akbari 2005), we will use an infrared surface temperature sensor to test the cool paint's effectiveness after we paint one of two identical bungalows owned by the Gump Station. If this paint proves effective, the Gump station has connections to hardware stores on the island, who may begin to stock this type of paint for use by a more general population.

EMBEDDED WIRELESS SENSOR NETWORKS

We have recently learned of a new sensor development by a UC Berkeley Professor, Kris Pister and his staff, that can be designed to measure multiple conditions simultaneously such as temperature, humidity, air velocity, lighting, energy consumption, and motion. These wireless sensors continually record and download data every minute and can transmit their data to the internet, which can then be analyzed from OPH headquarters as well as UC Berkeley (Kammen-May 1 2009, Pister-May 11 2009). These sensors are about the size of a quarter, virtually unnoticeable and does not affect daily life activities, and have a much lower maintenance and data logging schedule than other similar devices. They can be placed on walls, ceilings, windows etc, to test every possible condition on the various spaces and materials. With an internal battery life of about ten years, the sensors are an efficient and effective option for OPH to analyze new iterations of the current MTR as well as future models before distribution. We are currently working with Kris Pister's research group to find distributors who can provide the particular sensor types we are looking for. As suggested by Kris Pister, we also hope to add an electrical engineering student to our team who can design and build the printed circuit boards for the sensors to measure temperature, humidity, and airflow.

SEMI-STRUCTURED INTERVIEW

To keep the MTR in line with the social and cultural preferences and needs of the local communities, we are developing a semi-structured interview for the locals that will be administered through the help of local organizations. Currently, the interview consists of questions about their daily activities and level of comfort within the home. We also hope to track the activities that take place outside the home due to high interior temperatures as well as their personal suggestions to how the design could be improved. Each interview will be anonymous, and will be the basis of a post-occupancy evaluation that a future group, or OPH, could distribute and analyze. Additionally, after the month that we students spend in the MTR, community members will live in the MTR so that the activities and energy usage are accurate. This will be coordinated through the Associate Director of the Gump Research Station, Hinano Teavai-Murphy who is the president of a community-based organization that has expressed interest in living in the MTR since they are familiar with the uncomfortable state of the current kit houses (Davies). This qualitative semi-structured interview is one of the most important, if not the most important aspect of the project and needs extensive consideration to remain in line with cultural standards and habits. As an outsider coming into the community, it is key that we work with local organizations in approaching the community with questions about their personal life and habits.

DIGITAL MODEL

The digital Ecotect model (as well as other program models to be developed during the summer) will also be altered while we are on-site. As mentioned previously, there are discrepancies between the framing plans and the floor plans, so once we are able to see the built design we can update the building accordingly. We can then adjust the design digitally to see what the effect will be. Also, once we have acquired data from the continuous loggers and adequately understand the airflow in the house, we can use these as input data to create a more accurate digital model that generates more precise results. OPH has expressed interest in learning how to use these programs, so we will hold a seminar while on the island to introduce the government employees to building information modeling programs like Ecotect along with its benefits and how it can compliment design.

VI. Concluding Thoughts and Reflections

French Polynesia has extremely high living and property costs, yet average family income remains low, creating a demand for affordable housing. The MTRs are crucial in addressing this disparity and are increasing prevalent throughout the islands with over 3000 being constructed since 1996 (Davies). While these homes are one of the only housing options for many natives of French Polynesia it is essential that they are efficient in maintaining comfort and cyclone resistance. Ideally, the kit house will be locally produced and distributed, which would require a build up of industries on the island to support that process. Working with OPH has potential for large scale impact because small changes to the house design and function will affect the entire importation and production process.

When we continue our on-site research, we will be looking at the overarching societal issues the development of the kit house can address. Beyond the need for affordable housing, we hope to enhance the house by creating a design that fits the Native Polynesians' needs and lifestyle. We think it is critical to work directly with the community we are serving, in order to produce a home that they can use and are comfortable living in. Focusing on thermal comfort is an important factor because it can be addressed on older models as well. While thermal comfort is a qualitative and individual preference, it is essential to give the user more options that they can control. We are working across the board to include not just the overall enhancement of the house, but external factors that influence environmental change and lifestyle. While we continue to research and analyze specific project details, we constantly assess every action's plausibility and functionality within the larger scope of community needs within the societal, environmental, economic and political context of French Polynesia.

Finally, we hope to establish the necessary contacts, and gather the essential information to pass on to the future CE 290 Moorea group. We are compiling detailed contact lists, and data, so they can make the most out of continuing this project.

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Office of Polynesian Housing

Gump Station, French Polyneisia

VIII. Appendix

Cost Analysis of Gossamer Fan vs. Typical Fan

Assumptions:

- one fan in each bedroom (3 total) and two fans in the kitchen/living room
- based on the daily schedules that were reported from the 2007 DSC group's report (Meryman, 2007) and their travels in Moorea:
    - lightbulbs used are incandescent 60W bulbs
    - medium setting for the fan uses about 50W
    - cost of electricity is \$ .375/kWh
- Max:
    - All lights would be on for 8.5 hours per day
    - One light would be on for 15.5 hours per day (overnight security)
    - All of the fans would be on for 8 hours per day
- Min:
    - All lights would be on for 4 hours per day
    - One light would be on for 15.5 hours per day (overnight security)
    - All fans would be on for two hours per day

$$Max: \left((5\ lights) * \left(8.5 \frac{hours}{day}\right) + (1\ light) * \left(7 \frac{hours}{day}\right) \right) * \left(\frac{60W}{light}\right) * \left(\frac{1kW}{1000W}\right) * \left(\$.\frac{375}{kWh}\right) * \left(\frac{365d}{yr}\right) + (5\ fans) * \left(8 \frac{hours}{day}\right) * \left(\frac{50W}{fan}\right) * \left(\frac{1kW}{1000W}\right) * \left(\$.\frac{375}{kWh}\right) * \left(\frac{365d}{yr}\right) * (40\%) = \$272.11/year$$

$$Min: \left((5\ lights) * \left(4 \frac{hours}{day}\right) + (1\ light) * \left(11.5 \frac{hours}{day}\right) \right) * \left(\frac{60W}{light}\right) * \left(\frac{1kW}{1000W}\right) * \left(\$.\frac{375}{kWh}\right) * \left(\frac{365d}{yr}\right) + (5\ fans) * \left(2 \frac{hours}{day}\right) * \left(\frac{50W}{fan}\right) * \left(\frac{1kW}{1000W}\right) * \left(\$.\frac{375}{kWh}\right) * \left(\frac{365d}{yr}\right) * (40\%) = \$130.85/year$$

CFM → ACH calculations

$$Bedroom: \left(4200 \frac{ft^3}{min}\right) * \left(\frac{1m^3}{35.31ft^3}\right) * \left(\frac{Airchange}{40.138m^3}\right) * \left(60 \frac{min}{hour}\right) = 177.8\ ACH$$

$$Kitchen - Living\ Room: \left(8400 \frac{ft^3}{min}\right) * \left(\frac{1m^3}{35.31ft^3}\right) * \left(\frac{Airchange}{118.152m^3}\right) * \left(60 \frac{min}{hour}\right) = 120.8\ ACH$$

Total volume of bedrooms: 120.414m^3 from Ecotect model→one bedroom volume = 40.138m^3

Volume of kitchen/living roomL 118.152m^3 from Ecotect model

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